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PROMOTING DIRECTIONAL SOLIDIFICATION BY SELECTING PROPER CHILLS FOR RIBS AND BOSSES ON STEEL CASTINGS

Recent studies conducted at the Naval Research Laboratory have evolved a simple method for determining external chill dimensions to minimize hot spots created by ribs and bosses. This article is a summary of the studies by Pellini, Bishop and Myskowski.

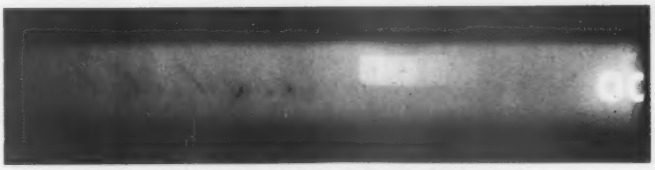


Figure 1—Centerline shrinkage in two-inch plate. Riser located at left.

The foundryman is very often confronted with the problem of a hot spot or shrinkage cavity which develops at a junction of two sections. The most desirable method in which the unfed hot spot may be removed is to chill the area sufficiently so as to allow directional solidification to take place. However, the choice of an external chill as to dimensions is a very critical one when ribs or bosses are being considered.

The test casting for the chilling studies was 10 inches wide, 13 inches long, and 2 inches thick. The riser selected for the plate casting was large enough to have the proper solidification time and volume. Although the riser was sufficient, it was located as a side riser so that it was only possible to feed 9 inches of the 13-inch length. The lack of proper feeding distance resulted in centerline shrinkage as shown in the cross section radiograph in Figure 1.

A rib was then attached in the unfed area 5 inches from the riser and 8 inches from the opposite end as shown in Figure 2.

This was done so that the rib would be located in a region beyond the zone of influence of either the riser or the casting end. The effect of the rib and the chills on the rib could then be determined without the complicating influences of the riser and the chill zone at the casting end.

The test casting with a rib 2 inches thick and 1 inch deep was cast with varying thicknesses of chills in order to observe the effects of the chills. Figure 3 are cross section radiographs of the test castings, showing the resulting solidification. The radiographs of Figure 3 must be compared with Figure 1. If the rib is chilled so that the shrinkage is located and similar to that of Figure 1, then the chill used would be considered to be the critical thickness necessary to neutralize the hot spot resulting from the position of the rib. Figure 3-OP illustrates that no chill was used. The result was that the shrinkage was concentrated at the hot spot produced by the ribs. A ¼ inch thick chill (Figure 3-4P) creates essentially an adequate condition since the shrinkage very closely approximates the amount shown in Figure 1. One-half and one inch chills illustrated in Figures 3-5O and 7P resulted in a condition of over chilling. The chilling in Figure 3-5O and 7P is so great that the "T" section solidified early and prevented feed metal from reaching the unfed section to its right.

The proper selection of chill thickness for a 2 inch rib 1 inch deep, therefore, would be ¼ inch. A difference of ¼ inch or a total of ½ inch chill thickness results in a casting condition which is as detrimental as no chill at all. This points to the fact that selection of the proper chill thickness is extremely critical for under-chilling is as undesirable as over-chilling.

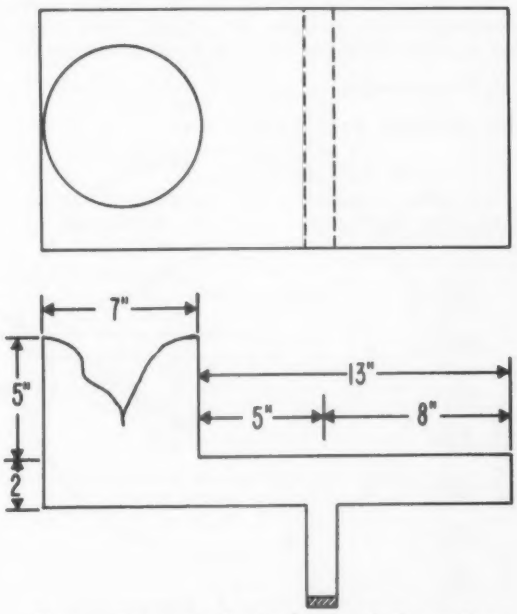


Figure 2—Test casting showing location of rib appendage and placement of chills.

Studies based on chilling a 3 x 3 inch boss 3 inches deep were investigated on a two-inch parent plate. These studies reveal that selection of a ½ inch chill thickness served to neutralize the hot spot effect.

Tests were made on ribs and bosses of varying thickness and depth. It was observed that the severity of the hot spot condition within the casting is intensified as the depth of the boss or rib increases.

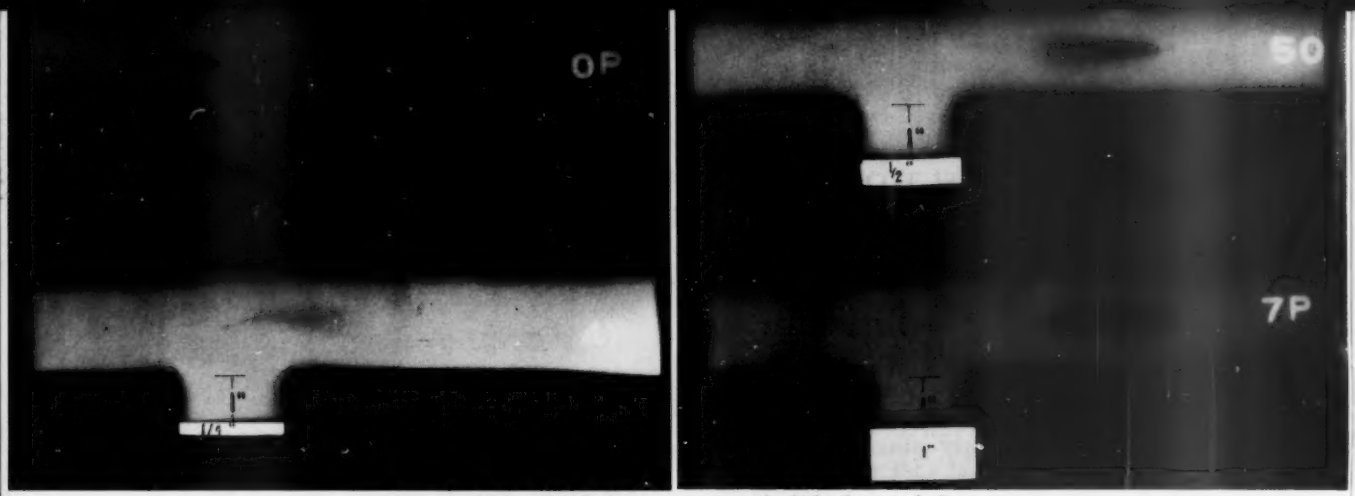


Figure 3—Effects of chill thickness on a 2-inch thick rib—1 inch deep.

The chart of Figure 4 was constructed from the data. By using this chart a rapid determination of chill thickness is possible for any size parent plate with rib or boss appendage. The chill thickness resulting is the necessary thickness to promote directional solidification in the parent plate.

The determination is based on "T" (parent plate thickness). For example; if a 4-inch thick plate has a 3-inch thick rib, 8 inches deep, the rib thickness is expressed as: $\frac{3''\text{ thick rib}}{4''\text{ thick parent plate}}$ or 0.75 T.

The appendage depth is expressed as:

$$\frac{8''\text{ deep rib}}{4''\text{ thick parent plate}} \text{ or } 2T.$$

A rib, whose thickness is .75 T and as a 2T depth, falls upon the chart as shown by the dotted line in Figure 4. The resulting chill thickness would be 0.32 T or 1.25 inches.

The chill thickness for a 6-inch boss, 8 inches deep attached to a 5-inch thick plate would be:

1. Boss thickness $= \frac{6''}{5''} = 1.2$ T
2. Appendage depth $= \frac{8''}{5''} = 1.6$ T
3. Chill thickness $= 0.10$ T (From Figure 4)
4. Chill thickness $= (.10)(5)$ or 1 inch

Several check castings were made in which casting dimensions were altered. Chill thicknesses found to be experimentally adequate when rechecked by calculation were found to be exactly as predicted by the chart in Figure 4.

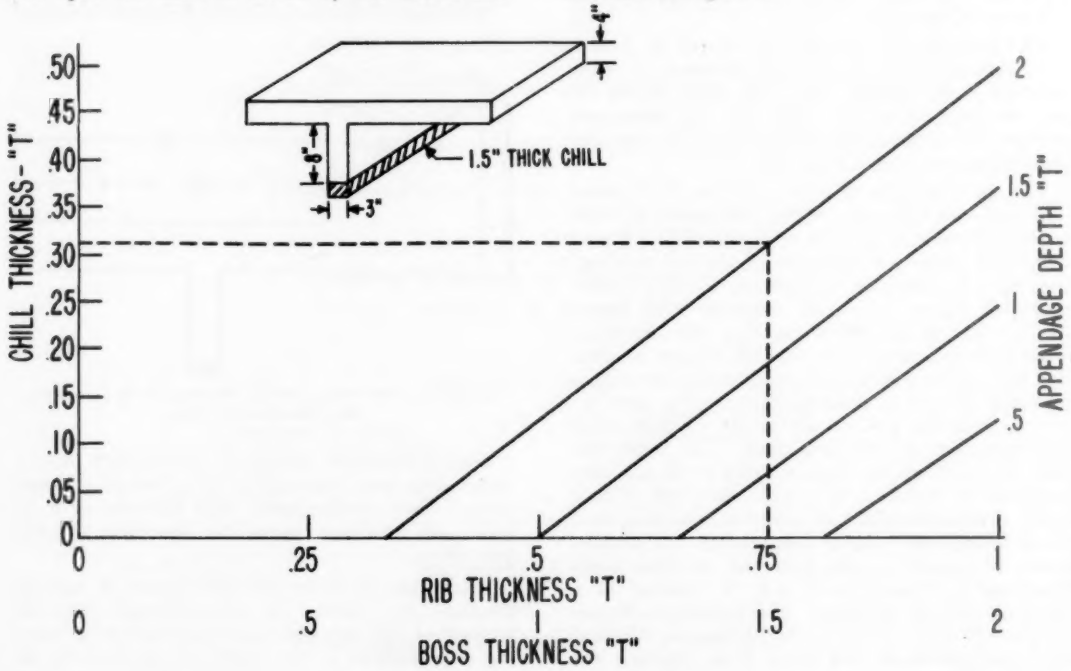


Figure 4—Chart for determining chill thickness.

STEEL CASTING RISERING PROBLEMS USING SIMPLIFIED METHOD

Journal issues numbers one and two discussed how minimum riser volumes and minimum riser dimensions for simple shaped castings with and without attached sections may be calculated. The method described was less time consuming than the original SFSA method of determining freezing ratios of various castings and more direct in obtaining a solution.

The purpose of this article is to present actual castings with riser dimensions which were determined by the simplified method.

Each riser problem has been outlined so that anyone computing riser sizes may become more familiar with procedures discussed in the previous issues of the Journal.

Two casting designs have been selected for this discussion, a crusher disc and a gear blank. The crusher disc has been chosen so that the possibilities of using one, two, three, or a ring riser may be discussed. The calculations for the gear blank typify the use of chills to increase feeding distance of the risers and compares this solution to one in which feeding is completed by selection and placement of risers.

CRUSHER DISC

The casting shown in Figure 1 is a disc for a crusher unit. Fundamentally it is a bar with a plate attached to it. It is suggested that two risers be employed for the first example of calculation.

Two Risers

1—If the hub section is considered as a riser for the plate, it will be observed that on the basis of a 4T feeding distance the plate can be fed by risers on the hub since the plate width is only 13 inches and $4T = 4(3\frac{3}{4}) = 15$ inches.

2—The centerline circumference of the hub is $\pi(5+16) = 66$ inches. A riser on the hub would feed 2T or 10 inches. This means that the distance between risers cannot be over 20 inches. If 2 risers are used then $66 - 40 = 26$ inches, the distance that must be covered by two risers of at least 13 inches diameter would be necessary. Also, since 2 risers are used on the casting, calculations can be based on one-half of the castings.

3—The volume of ½ hub:

$$V_h = \frac{\pi(13^2 - 8^2) \times 9\frac{5}{8}}{2} = 1597 \text{ cu. in.}$$

4—The volume of ½ the flange:

$$V_f = \frac{\pi(26^2 - 13^2)\ 3\frac{1}{4}}{2} = 2987 \text{ cu. in.}$$

5—Medium length of ½ hub $= \frac{\pi(5+16)}{2} = 33$ in.

6—Shape factor of the hub: L = length, W = width, T = thickness

$$(L + W)/T = (33 + 9\frac{5}{8})/5 = 8.5$$

7—The relation of the hub shape factor to minimum effective riser volume as a fraction of the casting volume is given in Figure 2 (see Figure 4, page 6, Journal of Steel Castings Research, Issue No. 1) with 8.5 shape factor a R_V/C_V value of 0.5 is obtained if the upper curve is used, which constitutes a very safe value. Thus the riser volume divided by the casting volume is $R_V/C_V = 0.5$

8—It has been said that the flange or plate section is appended to the hub or bar section. The ratio of the thicknesses of these two sections is:

$$\frac{\text{T flange}}{\text{T hub}} = \frac{3.75}{5} = .75$$

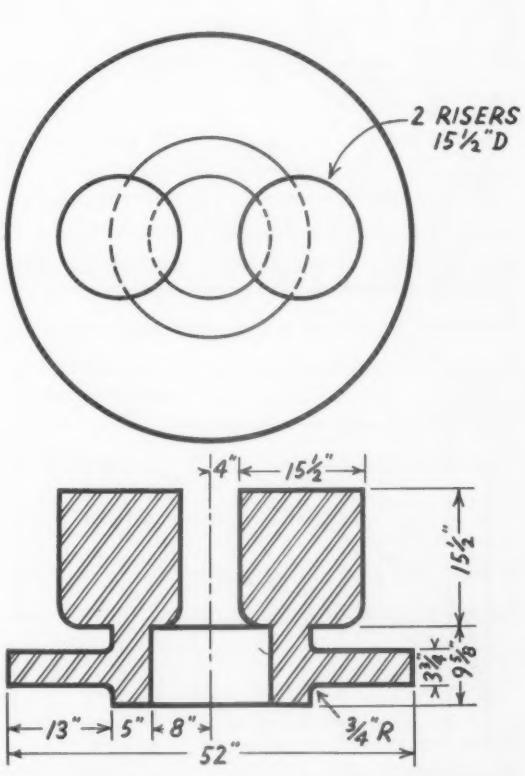


Figure 1—Crusher disc, two risers.

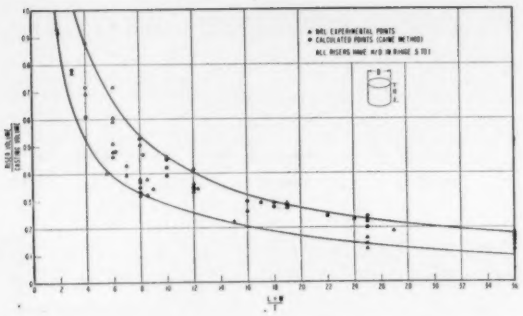


Figure 2—Relation of casting shape factor to riser volume as a fraction of casting volume.

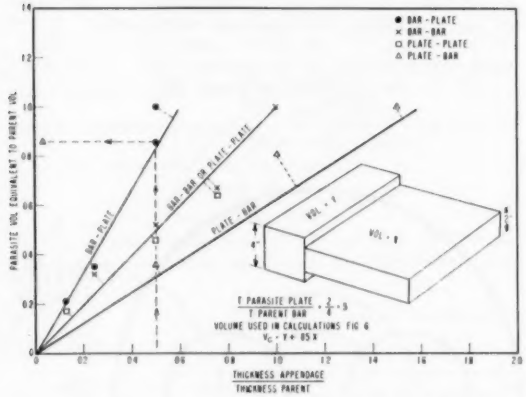

BAR - PLATE
BAR - BAR
PLATE - PLATE
PLATE - BAR
BAR - PLATE
BAR - BAR OR PLATE - PLATE
PLATE - BAR
VOL - I
VOL - II
T PARASITE PLATE = 2/4 = .5
T PARENT BAR
VOLUME USED IN CALCULATIONS FIG 6
Vc = Y + .05X
PARASITE VOL EQUIVALENT TO PARENT VOL
THICKNESS APPENDAGE / THICKNESS PARENT

Figure 3—Percent of appendage to be added to the parent volume to determine the minimum riser volume.

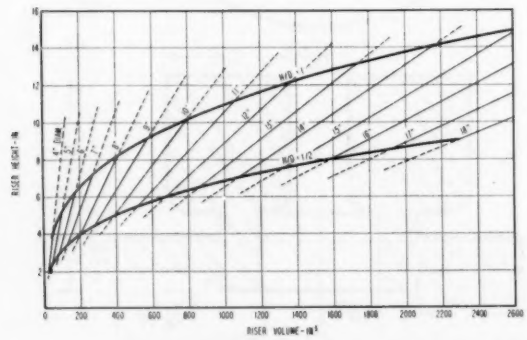


Figure 4—Chart for conversion of required riser volume to riser dimensions.

9—The percentage of the flange volume which must be added to the hub volume to determine the riser volume can be determined by applying Figure 3 (See Figure 15, page 3 of Journal of Steel Casting Research, Issue No. 2.). Use of .75 section ratio to the bar-plate line extended will give a value of 1.3 The flange volume to be used in the calculations is: 1.3 x 2987 = 3883 cu. in.

10—The riser volume = R_V = .5 (1597 + 3883) = 2740 cu. in.

11—The riser dimensions can be obtained by referring to Figure 4 (See Figure 5, page 6 of Journal of Steel Castings Research, Issue No. 1).

The Riser dimensions are 15½ inches diameter x 15½ inches high positioned as shown in Figure 1.

The large size of the risers, wherein a 15½ inch cylinder is positioned on a 5-inch section results in a molding problem and might not be acceptable to certain operating personnel. In such a case it would seem advisable to reduce the riser size by using more than 2 risers.

Three Risers

The calculations for the application of three risers to the hub area are set down in summary form as follows:

1—Volume ⅓ hub = 1065 cu. in.

2—Volume ⅓ flange = 1991 cu. in.

3—Medium length of ⅓ hub = $\frac{\pi(5+16)}{3}$ = 22 in.

4—Shape factor
$(L+W)/T = (22+9\frac{5}{8})/5 = 6.3$

5—R_V/C_V = .45 (From Figure 2)

6—T flange/T hub = 3.75/5 = .75

7—Percent of the flange volume added to the hub volume = 1.28 (From Figure 3)

8—Riser Volume
$= .45[1065 + (1.3)(1991)] = 1640$ cu. in.

9—Riser dimensions are 13 inches diameter x 13 inches high (From Figure 4) as shown in the sketch of Figure 5.

One Riser—Inside Hub (Internal Riser)

The calculations for the application of one riser inside the hub are set down in summary form as follows:

1—The volume of the hub = 3194 cu. in.

2—The volume of the flange = 5974 cu. in.

3—Medium length of hub = 66 in.

4—Shape factor $\frac{L+W}{T} = \frac{66+9\frac{5}{8}}{5} = 15.2$

5—R_V/C_V = 0.2 (From Figure 2)

In this case the lower limit of the band was used to determine the R_V/C_V ratio because with an internal riser the surface area will be greatly reduced thus justifying the lower limit of the band.

6—T flange/T hub $= \frac{3.75}{5} = 0.75$

7—Percent of the flange volume added to the hub volume = 1.28 (From Figure 3)

8—Riser Volume = 0.2 [(3194 + (1.3) (5974)] = 2190 cu. in.

9—Riser dimensions = 13 inch diameter x 17 inches high (From Figure 4) as shown in the drawing of Figure 6.

Ring Riser

The Surface Area/Volume ratio of a ring riser is $\frac{3}{T}$ or $\frac{3}{H}$, where T is the thickness and H is the height and H is equal to T. $(\frac{SA}{V} = \frac{3}{T} = \frac{3}{H})$

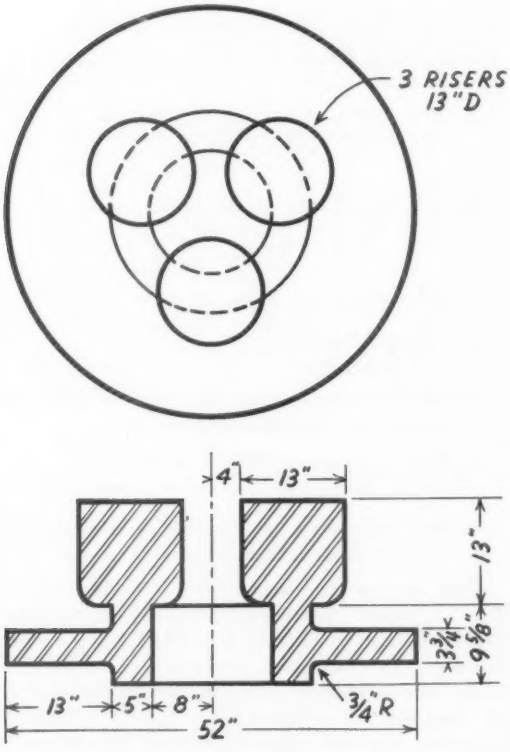


Figure 5—Crusher disc, three risers.

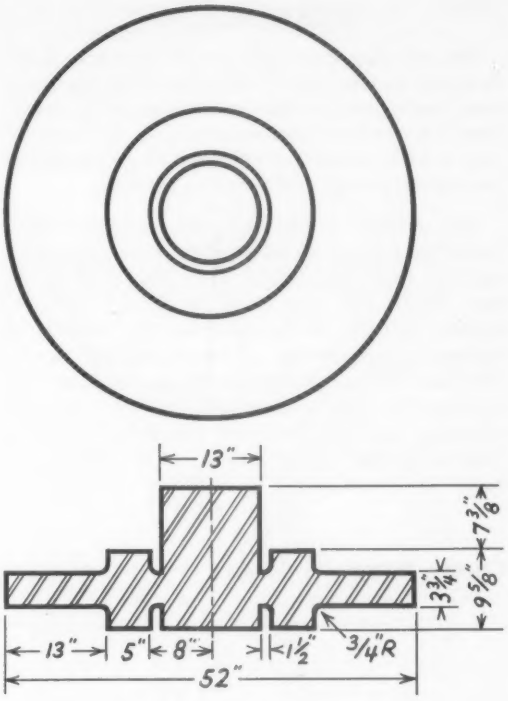


Figure 6—Crusher disc, one riser.

The dimensions of a ring riser for the disc casting can be calculated from the Surface Area/Volume ratio of a cylindrical riser. The Surface Area/Volume ratio of a cylindrical riser is equal to $\frac{5}{D}$ where D is the diameter of the cylindrical riser and is equal to the riser height. In the case of the 13 inch diameter internal riser, the Surface Area/Volume ratio is equal to $\frac{5}{13}$. The ring riser, therefore, must have a Surface Area/Volume ratio equal to $\frac{5}{13}$. By substituting $\frac{5}{13}$ in the equation $\frac{SA}{V} = \frac{3}{T}$ and by solving for T, it is found that T is equal to 8 inches. $(\frac{5}{13} = \frac{3}{T};\ T = 7.8)$.

The dimensions of a ring riser, therefore, would be 8 inches high and 8 inches wide, centered in the hub section as shown in Figure 7.

GEAR BLANK

The second casting design to be risered is shown in Figure 8. Because of customer requirements the outer surface and the bore must be perfectly sound; therefore, the first approach would be to position a riser at each one of the spoke and ring intersections and supply enough feed metal to the bore.

The method available for riser determination is limited to a parent section with an attached appendage. So that this method would lend itself to the gear blank, the gear blank is divided into two separate sections for calculations: the problem of feeding the outside ring and feeding the hub section. The two separate sections would be the outer ring considered as a parent bar with a 2 x 1.5 inch bar appendage attached; the other calculation would be feeding the hub section and it can be treated as a parent plate with a 3 x 1.5 inch bar appendage.

Outer Ring—6 Risers

1—The medium length of 1/6 the outer ring = $\frac{\pi(52\frac{1}{2})}{6} = 27.5$ in.

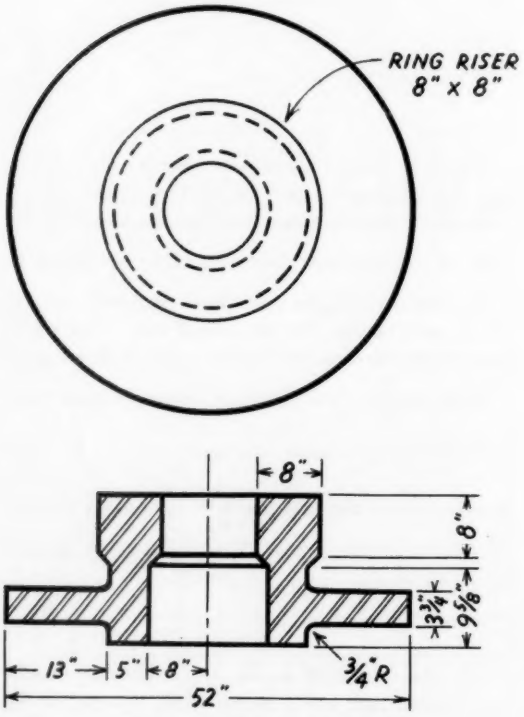


Figure 7—Crusher disc, ring riser.

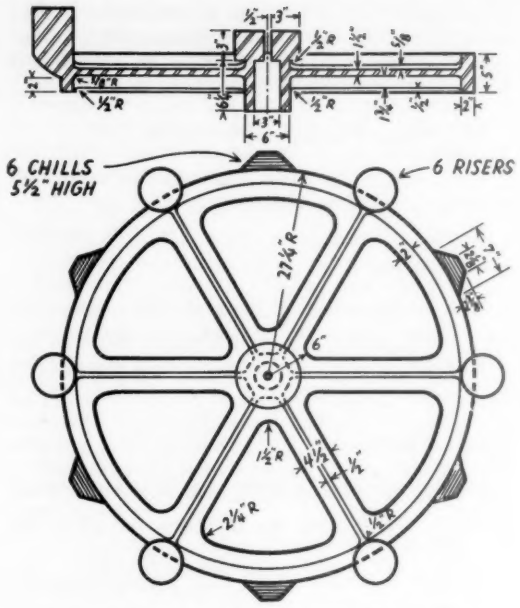


Figure 8—Gear blank, six risers with chills positioned.

2—The volume of 1/6 the outer ring = $\frac{\pi[(27\frac{1}{4})^2 - (25\frac{1}{4})^2] \times 5}{6} = 275$ cu. in.

3—The volume of 1/6 the attached bar = $\frac{\pi[(25\frac{1}{4})^2 - (23\frac{1}{4})^2] \times 1.5}{6} = 76$ cu. in.

4—The shape factor of the parent bar = $\frac{L+W}{T} = \frac{26.5+5}{2} = 16.3$

5—$\frac{C_V}{R_V} = .25$ (From Figure 2)

6—$\frac{\text{T appendage Bar}}{\text{T parent Bar}} = \frac{1.5}{2.0} = .75$

7—Percent of appendage bar volume added to parent bar = 0.8 (From Figure 3)

8—Riser volume = $.25[275 + .8(76)]$ = 86 cu. in.

9—Riser dimensions are 5 inches in diameter and 5 inches high. (From Figure 4)

Each segment of the ring has a median length of 27.5 inches. Each segment would be partially covered by the 5 inch riser which leaves 22.5 inches to be fed by two risers. Since two risers fed this length and contribute a feeding distance of 3.5 T per riser the total distance fed is 2 x 3.5 x 2 or 14 inches by the two risers. Centered between each riser is an area of 8.5 inches which is unfed.

There are three alternatives to relieve this situation: (1) increase the riser diameters, (2) chill the unfed zones, and (3) use a greater number of risers. The first solution is not economical in that a lower yield will result. The second would be a savings because the yield will remain the same and the only cost consideration would be the ram-up chills.

Knowing that soundness is increased by a chill, whose thickness is equal to ½ T of the bar section, for a distance of $12\sqrt{T}+2T$, where T is the bar section thickness, a maximum increase $12\sqrt{2}+4$ or 21 inches is possible. For this example the chill thickness of 2⅜ is more than adequate in chilling the previously unfed sections. The placements of chills and risers are shown in Figure 8.

Center Hub-Ring Riser

The hub section of the casting shown in Figure 8 is considered as a parent plate with an attached bar.

1—Volume of the center hub=
$\pi[(3)^2-(1.5)^2]$ x 6.25 = 132.5 cu. in.

2—Volume of the flange=
$\pi[(6)^2-(3)^2]$ x 1.5 = 127 cu. in.

3—The centerline circumference of the hub=
$\pi(4.5)=14.1$ in.

4—Since the core of the hub is equal to 2T where T is the thickness of the parent plate, the effective thickness Te is calculated from Table I (See Figure 19, page 3 Journal of Steel Casting Research, Issue No. 2).

$Te=1.10 \times T=1.10 \times 1.5=1.65$ in.

5—The shape factor

$$\frac{L+W}{Te}=\frac{14.1+6.25}{1.65}=\frac{20.35}{1.65}=12.3$$

6—$\frac{R_V}{C_V}=.39$ (From Figure 2)

7—$\frac{\text{T appendage bar}}{\text{T parent plate}}=\frac{1.5}{1.5}=1.0$

TABLE I—Thickness Correction for Cored Castings

Core Diameter*	Correction Factor	Example (4" Wall)
½ T	1.17	4.7
T	1.14	4.5
2 T	1.10	4.4
4 T	1.02	4.1

**Core diameter as a fraction of parent section thickness "T"*

8—Percent of appendage bar volume added to parent volume = 0.6 (From Figure 3)

9—Volume of the riser=
.36 [(132 + .6(127)] = 75 cu. in.

10—Dimension of a cylindrical riser is 5 inches in diameter and 5 inches high. (From Figure 4).

11—Dimensions of a ring riser, in which the height equals the width, previously discussed, would be equal to 0.6 times the diameter of a single circular riser or (.6) x (5) equals 3 inches in height and width positioned as shown in Figure 8.

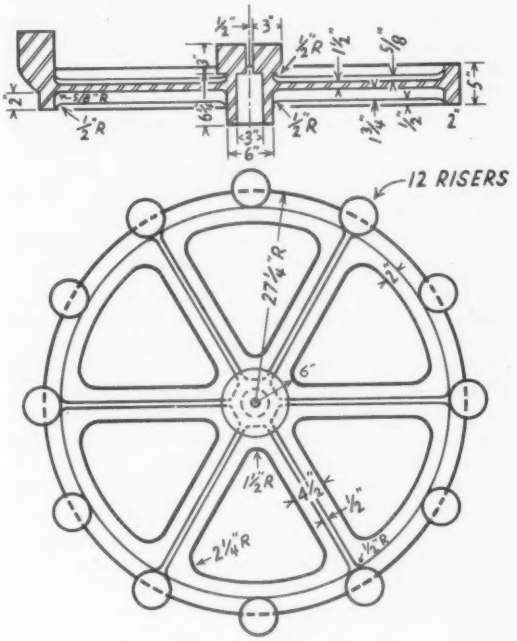


Figure 9—Gear blank, twelve risers.

Outer Ring—12 Risers

1. Volume of 1/12 outer ring = 138 cu. in.
2. Volume of 1/12 attached plate = 38 cu. in.
3. The median length of 1/12 outer ring = 13.8 in.
4. Shape factor of parent bar =
$$\frac{L+W}{T}=\frac{13.8+5}{2}=9.4$$
5. $\frac{R_V}{C_V}=0.5$ (From Figure 2)
6. $\frac{\text{T appendage bar}}{\text{T parent bar}}=\frac{1.5}{2.0}=.75$
7. Percent of appendage bar volume added to parent bar volume = 0.8 (From Figure 3)
8. Riser volume = .5 [(138) + .8(38)] = 84 cu. in.
9. Riser dimensions are 5 inches diameter and 5 inches high (From Figure 4) and positioned as shown in Figure 9.

PROPERTIES OF TS 8630 (Ni-Cr-Mo) CAST STEELS

The Technical Research Committee of the Steel Founders' Society of America initiated, at Case Institute of Technology, an investigation of the physical properties of three of the more popular and promising lean alloy cast steels. In the first issue of the "Journal of Steel Castings Research" the data for TS-8130 cast steel were presented; and, in the second issue information on 6130 cast steel was given.

The TS 8360 steel was proposed by the American Iron and Steel Institute and the properties of this steel are presented in this issue of the Journal—No. 3. This report presents the tensile properties, the Charpy V-Notch impact properties at 74 degrees F and at –40 degrees F., the hardness values and the hardenability curves. The study included section sizes of one inch and four inches.

Four separate heats of TS 8630 cast steel were produced: one by the acid open hearth process; one by the basic open hearth process; one by the acid electric process; and one by the basic electric process. Each foundry cast keel blocks in one inch sections and, in addition, the acid electric producer cast four-inch specimens from the same heat as the one-inch sections. All four foundries forwarded the keel block coupons in the as-cast condition to Case Institute of Technology for investigation.

Both the one-inch and four-inch cast coupons were heat treated by the laboratory prior to machining. The heat treatments for the one-inch coupons were: (1) normalizing from 1650 degrees F and tempering at 1200 degrees F.; (2) normalizing, water quenching from 1575 degrees F and tempering at 1000 degrees F; (3) normalizing, water quenching from 1575 degrees F and tempering at 1200 degrees F. The four inch sections were heat treated similarly to (1) and (3) above. All one-inch sections were held at temperature for 1½ hours and the four inch sections were held at temperature for 4 hours. The tempering operation was followed by a water quench.

Chemical Composition

The chemical range for TS 8630 as specified for steel castings is as follows:

C	0.28 - 0.33
Mn	0.70 - 0.90
Ni	0.40 - 0.70
Cr	0.55 - 0.75
Mo	0.08 - 0.15
Si	0.30 - 0.60

The ladle analyses of the four heats are presented in the table of Figure 1. The composition of the four steels is within specifications except for a high chromium content in the heats produced by the acid electric and basic open-hearth processes.

TABLE I—Mechanical Properties of TS 8630 Cast Steel (One Inch Section)

Steelmaking Process	Tensile Strength psi	Yield Strength psi	Elong. in 2" %	Red. of Area %	BHN	Charpy V-Notch Ft-Lbs. at 74°F	Charpy V-Notch Ft-Lbs. at -40°F
Normalize (1650°F) and Temper (1200°F)							
Basic Open-Hearth	106,500	80,500	21.7	46.0	229	34.5	14.0
Acid Open-Hearth	104,000	74,000	19.5	39.0	217	11.0	4.5
Basic Electric	105,000	80,000	19.7	44.1	207	30.5	13.5
Acid Electric	115,500	89,500	16.7	41.1	248	21.0	10.0
Water Quench (1575°F) and Temper (1000°F)							
Basic Open-Hearth	158,000	144,500	13.5	34.3	331	.....	.....
Acid Open-Hearth	150,000	133,000	12.3	30.1	321	.....	.....
Basic Electric	155,500	144,500	11.8	31.6	321	.....	.....
Acid Electric	165,000	154,000	9.8	25.5	352	.....	.....
Water Quench (1575°F) and Temper (1200°F)							
Basic Open-Hearth	126,000	107,000	22.8	52.1	262	55.0	51.0
Acid Open-Hearth	126,500	109,000	15.0	36.8	262	33.0	22.0
Basic Electric	126,000	108,000	17.8	43.2	248	58.0	51.0
Acid Electric	132,500	114,500	17.7	41.5	277	37.0	32.0

Mechanical Properties

The mechanical properties of the TS 8630 cast steel, that is, tensile properties, Charpy V-Notch and hardness values, are listed in Table I according to melting practice and variations in heat treatment. The regular .505 inch diameter tensile and Charpy V-Notch impact specimens were prepared from the approximate center of the one-inch section coupons.

The data in Table I indicates that a wide variation in the tensile properties of TS 8630 are possible by varying the heat treatment, and for a given heat treatment the tensile properties are quite similar for the various steelmaking processes.

The yield/tensile ratio for all heat treatments and section sizes is listed in Table II. The high value obtained with the water quench and 1000 degree F temperature indicates this steel is essentially through-hardening for sections up to one-inch. Increasing the tempering temperature to 1200 degrees F lowers this ratio. The decrease in the yield/tensile ratio was less than the TS 8130 cast steel exhibited, but it was greater than in the case of the 6130 cast steel. The TS 8630 steel exhibited its highest yield/tensile ratio of the three steels investigated when the heat treatment consisted of a normalize and temper.

STEEL-MAKING PROCESS	C	Mn	P	S	Si	Ni	Cr	Mo	Cu	Norm. Temp. °F.	Quench Temp. °F.
O Basic Open-Hearth	.31	.84	.019	.019	.52	.66	.82	.15	—	1650	1575
X Acid Open-Hearth	.32	.65	.038	.034	.46	.53	.59	.14	.13	1650	1575
□ Basic Electric	.32	.75	.016	.009	.35	.65	.70	.14	—	1650	1575
△ Acid Electric	.31	.83	.019	.031	.30	.68	.78	.14	—	1650	1575

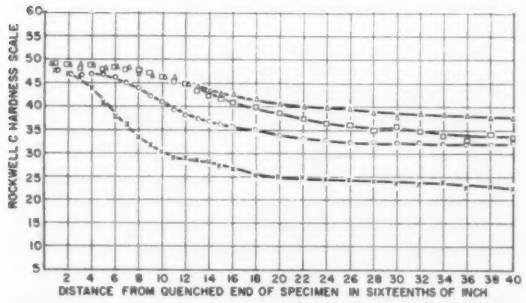


Figure 1—Jominy hardenability curves for various heats of cast TS 8630 steel.

Effect of Mass on TS 8630 Cast Steel

The effect of mass on the mechanical properties of TS 8630 cast steel was determined by taking test bars from approximately the center of 4 x 4 x 10 inch test coupons. In Table III the physical properties obtained from the test coupons cut from the four-inch specimen are recorded as well as the data regarding one-inch sections.

The four-inch section has slightly lower strength and ductility than the comparable one-inch section in both the normalize and tempered, and quenched and tempered condition. This mass effect is to be expected and results from such factors as variations in the casting rates, soundness hardenability, and segregation.

TABLE II—Yield-Tensile Ratios for TS 8630 Cast Steel

Steelmaking Process	Section Size	Water Quench 1000°F Temper	Water Quench 1200°F Temper	Normalize 1200°F Temper
Basic Open-Hearth	1 inch	.92	.86	.75
Acid Open-Hearth	1 inch	.89	.86	.71
Basic Electric	1 inch	.92	.86	.76
Acid Electric	1 inch	.93	.86	.76
Acid Electric	4 inch	....	.82	.72

The impact properties of the one-inch and four-inch section for a given heat treatment exhibit little variation between the two section sizes. In fact, at room temperature the impact values for the four-inch section are superior to those obtained from the one-inch sections.

TABLE III—Effect of Mass on Mechanical Properties of TS 8630 Cast Steel Produced by Acid Electric Process

Section Size	Tensile Strength psi	Yield Strength psi	Elong. in 2" %	Red. of Area %	BHN	Charpy Impact Ft-Lbs. at 74°F	Charpy Impact Ft-Lbs. at -40°F
Normalize and Tempered at 1200°F							
1 inch	115,500	89,500	16.7	41.1	248	21	10
4 inch	103,500	74,500	13.0	31.5	223	25	10.5
Water Quenched and Tempered at 1200°F							
1 inch	132,500	114,500	17.7	41.5	277	37	32
4 inch	129,000	105,500	15.0	34.1	269	41	22.5

End Quench Hardenability

The end-quenched hardenability curves for the four heats are plotted in Figure 1. All four heats have the same maximum surface hardness but the acid open-hearth heat shows an appreciably lower hardenability. The reason for this is the lower total alloy content of the heat.

Charpy V-Notch Properties of TS 8630 Cast Steel

The impact strength at room temperature and –40 degrees F is plotted in the form of bar graphs for all four heats and section sizes in Figure 2. The steelmaking process has a definite effect on the impact values. In all cases the impact values for the steels produced by either the basic electric or basic open-hearth are far superior to the values obtained from the steels melted by the acid processes. The superior impact values obtained by the basic melting processes are due primarily to the low sulfur and phosphorus content of these steels. As would be expected, the quenched and tempered steels exhibit the highest values and indicate a large improvement over the normalized and tempered steel at both room temperature and –40 degrees F.

Summary of the Three Low-Alloy Substitutes

A review of the data in the first three issues of "Journal of Steel Castings Research" indicates a wide range of tensile properties are possible by varying the heat treatments. The tensile strength may vary from 55,000 to 180,000 psi while the yield/tensile strength ratio for the one-inch section varies from .06 to .75 in the normalized and tempered condition and from .80 to .93 in the water quenched and tempered condition.

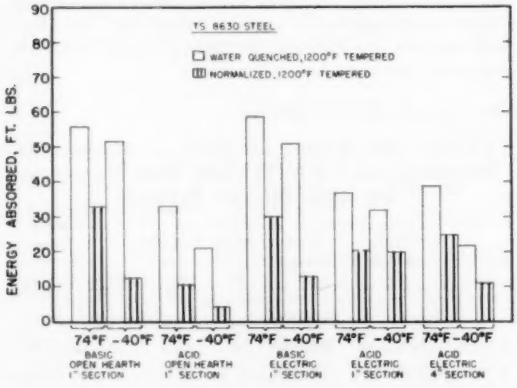


Figure 2—Charpy V-notch impact strength of different grades of TS 8630 steel with various heat treatments. tested at 74° and -40°F.

The relationship between the tensile strength and ductility (reduction area) for the water quenched and tempered, and the normalized and tempered conditions are plotted in Figure 3. As is well known, quenching to a martensitic structure and tempering produces a better combination of strength and ductility than does normalizing and tempering. This is evident in all three low alloy steels. The TS 8630 steel appears to exhibit a slightly superior combination of strength and ductility.

In Figure 4 the typical hardenability curves for each of the three steels investigated are plotted and, as can be readily observed, the hardenability does differ markedly. The TS 8630 has the greatest depth of hardenability as well as the highest surface hardness.

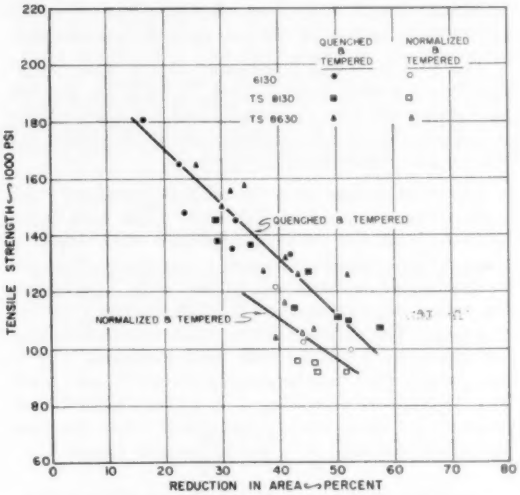


Figure 3—Relationship between tensile strength and ductility for various substitute cast steels (one inch section size).

TYPE	STEEL-MAKING PROCESS	C	Mn	P	S	Si	Ni	Cr	Mo	V	Norm. Temp. °F.	Quench Temp. °F.
6130	Basic Electric	.26	.78	.021	.025	.56	.047	.84	.038	.19	1675	1600
8130	Basic Electric	.28	.73	.023	.017	.47	.33	.39	.13	—	1650	1575
8630	Basic Electric	.32	.75	.016	.009	.35	.65	.70	.40	.14	1650	1575

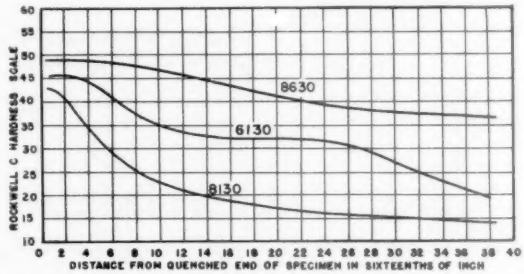


Figure 4—Jominy hardenability curves for three low alloy substitute cast steels as indicated.

A review of the impact data indicates that the 6130 steel has poor impact properties and as a substitute for a low-alloy molybdenum steel (8000 and 8400 series) offer little promise if impact properties

(Continued on Page 16)

MOLDING SAND GEOMETRY

One phase of the studies at the University of Kentucky on Research Project No. 31 on "A Study of Fundamentals of Steel Foundry Sand Control" was the investigation of the behavior of 4-sieve sands. A 4-sieve sand is one which contains more than 10 percent of the sand sample on four adjacent sieves. For example, the following sand would be classed as a 4-sieve sand:

Sieve	Percent
40	1.9
50	10.2
70	32.8
100	37.3
140	11.8
200	4.4
270	0.8
Pan	0.8

Sands of this type, bonded with bentonite and water and thoroughly mulled, develop green compression strengths that are considerably higher than usually found for other sands. They also develop high hardnesses and uniform hardness molds.

It also has been observed that these sands have been secured primarily by the blending of two sands. It seems that by this method it is easier to secure the desired 4-sieve combination in an economical manner. The new sand blend must be mulled for extensive periods of time. Recirculating and reworking of the sand in the system will produce the desired appreciable increase in green strength, flowability, and mold hardness.

The reason new sand mixes fail to possess extraordinary physical values is because the orderly packing of the rammed synthetic sand mixture has not been obtained.

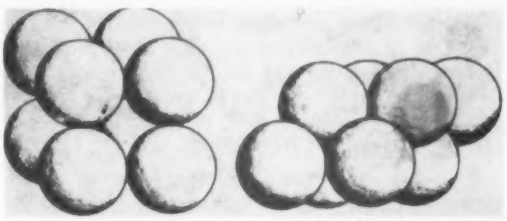
Orderly packing is a term given to sand grains which touch as many other sand grains as is possible. This may be done only if consideration is given to the particle sizes, shapes and surface conditions of the sand. Such a sand, if subject to mulling for a sufficient length of time, tends to produce a sand distribution compatible with good packing characteristics. Mulling also reduces the dimensions of oversize particles and simultaneously creates suitable sizes of smaller particles.

The pushing, mixing and kneading of the sand grains goes on until the small particles are in the voids between the larger grains. Compacts of this type have cohesion between the grains and the presence of plastic bonds permits the closely packed grains as an agglomerate unit to have toughness and strength.

The filling of voids between the grains is dependent upon particle size of the grains and the mulling of these grains. High packing pressures do very little towards filling the voids between the grains. These pressures squeeze the grains into a packed mass but they do not closely pack sands that are not well distributed. In lieu of resorting to high molding pressures, it is wiser to provide sufficient void-filling particles by controlling size distribution. The presence of too-uniform sizes of grains within a sand mixture can contribute to bridging, the creation of voids, surface roughness of the casting, and probably excess casting rejects.

Close packing obtained by thorough mixing and mulling permits the sand grains to be gathered into sub-assemblies which are then interlocked by pressure through the molding operation into large agglomerates.

An understanding of the requirements of the close packing of a molding sand is difficult because the sand that passes one sieve and falls on the next finer sieve consists of a number of sizes. However, the process of close orderly packing can be easily understood if uniform sized spheres are used as examples. The spheres would pack to create either simple cubic or rhombic formations as indicated in Figure 1.



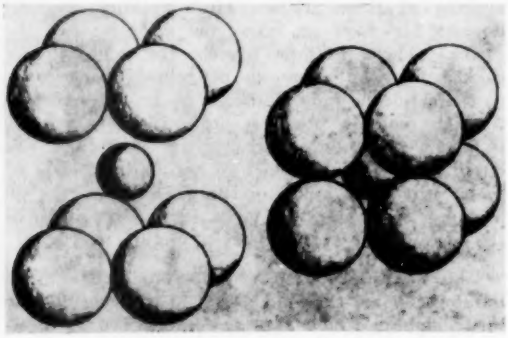
Cubic Rhombic

Figure 1—Types of packing of uniform size spheres.

The space within the center of the cubic formation can be readily seen. Into this space a smaller sphere can be fitted as shown in Figure 2. If this sphere is of the proper size it will contact all of the eight larger spheres without distorting the geometrical perfection of the cubic structure. Comparison would reveal that the included sphere in the rhombic structure would be smaller than the included sphere in the cubic formation.

The next step in this understanding is to assume that the sand is perfect spheres of diameters compatible with standard sieve openings. The spherical sand grains equal to a No. 70 sieve opening will require a sphere grain from the No. 100 sieve to create the required cubic formation or a sphere from the No. 140 sieve to be compatible with the creation

of the rhombic formation. In other words, a sphere of the next smaller sieve will fit the cubic arrangement but a sphere from the second-smaller sieve is necessary to fit into the rhombic cavity.



Expanded Formation Compact Formation

Figure 2—Cubic packing of uniform spheres from two adjacent sieves (a 2-sieve system).

This discussion of the 2-component systems can be extended to the more complex orderly packing arrangements peculiar to 3, 4, 5 and 6 component systems. This is not necessary, however, because it is believed that orderly formations created from 2-component systems predominate when mixing and mulling is applied to foundry sand mixtures.

A 2-sieve sand on the basis of the cubic packing would have 71.8 percent by weight on the No. 70 sieve and 28.2 percent on the No. 100 sieve. Unfortunately, graded sands are unable to meet the standards of perfection set for uniform size spheres. But the figures can be used as guides in selecting available washed and graded sands.

A 2-sieve sand would be impractical to obtain. However, it is possible—through sand blending—to obtain a 4-sieve sand. A large concentration of sand is desired on one particular sieve with diminishing percentages on the other sieves. Also, the probability of combining compatible grains can be increased if the presence of too large and too small grains is limited.

A 4-sieve sand of the following distribution would quality as to the necessary requirements:

No. 50 sieve	10 percent
No. 70 sieve	40 percent
No. 100 sieve	30 percent
No. 140 sieve	20 percent
	100 percent

About 70 percent of the total grains of this distribution will tend to behave as large grains and 30 percent will behave as comparatively small grains. The close order of packing and its subsequent advantages cannot be attained unless rounded or sub-angular sand is used. The angular grains do not lend themselves to readily creating orderly close-packed colonies during mulling.

Property Improvements

The placing of a smaller sand grain in the cubic or rhombic arrangement improves the rigidity and stability of the formation as the smaller grain serves as a key between the two layers of larger grains. The smaller grain is occupying space that might be filled by ineffective bond material. Maximum efficiency in bonding material requires that the binders be present as coatings on the sand grains. The bond adhesion and cohesion is most effective at the grain-to-grain contact. The contact is increased from 12 points to 20 in the simple cubic formation when the "key" grain is in place. The increased points of contact contribute a 66 percent improvement in strength potential with respect to improving bond efficiency.

An estimate of the increased property possibilities can be obtained through a controlled experiment using bonded uniform size glass beads. One group of beads was of a single size, No. 70 sieve, whereas the other group consisted of a blend of beads on No. 70 and No. 140 sieves. Both batches were bonded with 3 percent bentonite and 1.8 percent water and mulled for various times and tested in green compression. The results obtained are illustrated in Figure 3.

Both mixes improved in strength with mulling time. This was to be expected since the bentonite

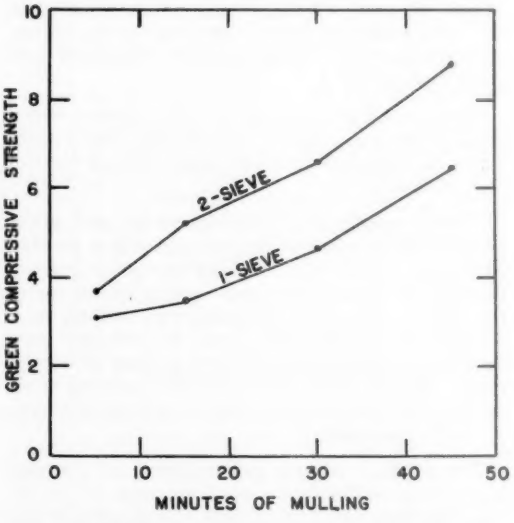


Figure 3—The effect of mulling time on the green compression strength of glass beads bonded with 3 percent bentonite and 1.8 percent moisture. The 2-sieve system consists of beads from No. 70 and No. 140 sieves blended together. The 1-sieve system consists of beads from the -50, + 70 sieve.

tempers under conditions of moisture; but the 2-sieve mix developed a 55 percent increase in strength over the uniform size particle. The strength increase was not immediate but required time for grain alignment through mixing and mulling. Gradually, as the mulling progressed, the smaller beads were able to find positions among the larger beads.

Close order packing of sands is possible in the steel foundry of today. The quality control necessary to maintain the system is considerable but the production and test equipment necessary for the quality control is available. Their use is certainly indicated in view of the surface requirements that are being specified for steel castings.

RESEARCH PROGRAM
RECENT PROGRESS REPORTS ON ACTIVE PROJECTS

Research Project No. 38

The Shell Molding Process for Plain Carbon and Low-Alloy Steel Castings

Research Report No. 34 covering an investigation on the shell molding process for carbon and low-alloy cast steels was forwarded to the member companies on about August 20, 1955. Extra copies of the report are available by writing to the Society.

The report contains information concerning surface defects on carbon and low-alloy steel castings, produced in resin-bonded shell molds, and the effects of variables that influence their occurrence. The following summary of the conclusions reached are recommended for general industrial use:

1. The surface finish of carbon and low-alloy steel castings is improved by using a minimum of resin binder in the shells. It is recommended that from 4 to 6 percent of two-step phenol formaldehyde resin be employed.
2. The addition of manganese dioxide to the shell molding mixture greatly improves steel casting surfaces. The MnO_2 content should be one-half of the resin content. An MnO_2 content of 80 percent or better should be used. If the content is below this value, lead dioxide (PbO_2) equal to one-half of the MnO_2 content should be added.
3. Calcium and sodium carbonates also show excellent results in preventing the formation of surface defects. The carbonate content should be one-half of the resin content.
4. Silica sand of a similar fineness of present practice green sand should be used if chemical additives are made a part of the mix.
5. Zircon sand and forsterite refractory produces excellent casting surfaces for casting section thickness greater than those where silica sand is applicable.
6. A fast-pouring rate and a high-pouring temperature is advantageous. The use of multiple ingates or any other method that will permit the mold cavity to be filled instantaneously is recommended.
7. High venting ability of shell molds is desirable. Thin shells, coarse sand, and composite molds are suggested. Molds should not be buried in heap sand for pouring.
8. High-alloy cast steels, carbon and low-alloy cast steels of carbon content less than about 0.30 percent, when cast in normal shell molds, will carburize at the casting surface. The lower the carbon content of the steels the greater the surface carburization. The addition of MnO_2 to the shell molding mix will prevent or lower perceptibly the carbon pickup in the casting skin.
9. Over-curing of baked molds or hot molds, the use of washes, or the use of grain refiners is not particularly advantageous in correcting defective surface conditions on steel castings.
10. A tolerance within 0.004 inch per inch may be expected for simple design steel castings. A tolerance of 0.006 or 0.007 inch per inch is probably a more reliable figure for intricate castings.

Research Project No. 33

Blast Cleaning of Steel Castings

The Technical Research Committee recognized that there was a need, in the steel casting industry, for a careful, unbiased appraisal of the various types and brands of abrasives and cleaning machines. The research program was conducted at Battelle Memorial Institute and four member companies were to supply this information.

A series of field tests was designed so as to disclose the relative merits of different types of metal abrasives as blast-cleaning media and to test their effects on cleaning efficiency and economy. Data were

gathered under commercial conditions in steel foundries making different types of castings.

Four foundries were selected to perform the tests and, in each foundry, the tests were performed by use of a different type of cleaning machine. The general testing procedure consisted of:

(1) Cleaning out the machine and loading it with the abrasive to be tested;

(2) Studying the normal blasting operation using various abrasives for a period of 30 days.

During the testing period, data were recorded covering abrasive additions, machine hours of operation, replacement of machine parts, electric power or air consumption, loads or tons of castings cleaned, maintenance time, and operator time. Abrasive consumption in pounds per hour was determined by plotting abrasive additions versus cumulative time. The slope of the straight portion of the curve was taken as the true consumption rate.

Certain laboratory tests were performed on samples of the abrasives tested in the foundries for purposes of establishing possible correlations between laboratory tests and foundry results. Such correlations would be desirable in establishing standards of quality for the selection and purchase of abrasives by foundries. The laboratory tests consisted of screen analyses, abrasive breakdown tests, hardness determinations, metallographic examinations, and chemical analyses.

Abrasive breakdown data obtained in the laboratory could not be correlated with foundry consumption rates of abrasive, apparently because of the differences in conditions existing in the laboratory machine as compared with those in a commercial blast cleaning machine.

Hardness data and metallographic studies appear to be the most useful tools in making a qualitative study of abrasives. The results of the test work in the foundries indicate that the most desirable type of microstructure to give long abrasive life and adequate cleaning characteristics is a slightly malleablized and highly spheroidized structure with an average hardness of about 425 Vickers. The life and cleaning characteristics of the cast steel and cut-wire abrasives tested on this project are not enough better than those of a properly malleablized abrasive to warrant their higher cost. This situation exists largely because of carry-out losses and loss of shot by leakage from machines.

A general observation is that waste of abrasive by carry-out and leakage is the determining factor in the selection of abrasives. Cut-wire and cast-steel abrasives are economically feasible only in those operations where waste has been reduced to a minimum. They were found to have been superseded at the four test foundries by malleable-iron or chilled-iron abrasives.

It appears that some foundries that have tested abrasives do not really know what their normal consumption rates for abrasives are, because tests have been too brief. The same is true of maintenance costs.

Other observations that can be drawn from the studies are as follows:

(1) Proper adjustment and maintenance of the separator is most important if the abrasive is to function at high efficiency.

(2) Savings in air consumption by use of long-life nozzles has been overemphasized.

(3) Hose wear in room-type airblast equipment may be the largest single cost item.

(4) Cleaning efficiency in terms of surface finish produced is difficult to define and depends upon the standards of surface cleanliness required. Where rather superficial cleaning is required, all types of abrasives do reasonably well. If standards are high, times required to attain the required finish are different for different abrasives. In general, chilled iron and malleable iron clean slightly faster than steel or cut wire.

(5) Wear studies of wheel parts in the centrifugal type of blasting machine indicate that the rate of wear is a straight line function of the time of operation and does not change significantly with a change to another type of abrasive of the same size. Furthermore, the studies indicate that the present impeller design is the cause of rapid blade destruction by channeling.

(6) Nozzles on airblast equipment tend to wear slightly faster when harder abrasives are used. Hose wear rates are more dependent upon abrasive particle shape than on abrasive hardness. The faster rates of hose wear were experienced with the grit types of abrasives.

The research studies have been completed and the report on these studies has been made to the Technical Research Committee. This Committee has completed its review of the report and has scheduled the report for preparation as a publication to the Society. It is hoped that the report will be available to the member companies about the end of this year. The cost of the 2-year program of research to date is $46,152.58. Publication costs will be added to this amount.

The Battelle report consists of over 200 pages including over 80 illustrations and a similar number of tables, hence blue book preparation will be time-consuming.

Research Project No. 25

Studies of Fatigue Properties of Cast and Wrought Carbon Steels

Inasmuch as there appeared to be a lack of data on the fatigue properties of cast steels, the Steel Founders' Society of America contemplated an extensive research program to provide information on the fatigue properties of cast and wrought steels. Therefore, in order to make adequate data on the mechanical properties of both materials available to the designer and producer of engineered parts, a study on "Fatigue Properties of Comparable Cast and Wrought Steels" was instigated at Case Institute of Technology.

The bulk of the work was divided into four main parts covering common factors that might have an influence on the fatigue performance of cast and wrought, carbon and low-alloy steels. The factors studied were:

(1) Effect of Steel Composition and Heat Treatment

(2) Effect of Surface Finish

(3) Effect of Directionality

(4) Effect of Section Size

The work covered in this progress report constitutes the preliminary program which served as a basis for the more extensive program. The primary purpose of this investigation was to determine the similarity or difference between comparable cast and wrought steels.

The original intent of this study was to determine the endurance limit* of cast and wrought steels of similar carbon content. This objective was altered when it was found that the cast steels exhibited higher tensile strengths than wrought steels of the same carbon content. Since there is a definite relationship between tensile strength and endurance limit, cast steels covering a range of carbon from 0.20 to 0.30 percent, and wrought steels of 0.30 to 0.40 percent carbon content were tested (in the four main parts of the investigation) so that fatigue properties could be evaluated on the basis of comparable tensile strengths as well as carbon content.

Six heats of carbon steel were tested in the normalized and tempered condition for hardness, tensile properties and fatigue characteristics. The chemical analyses and method of manufacture are given in Table I, and the hardness, tensile and fatigue results are reported in Table II. Standard R. R. Moore fatigue specimens, 0.220 inch minimum diameter, tested in an R. R. Moore high-speed rotating beam fatigue machine, were used to obtain the endurance limit.

The endurance limit (maximum stress at which the specimen withstood ten million (10^6) stress reversals without failure) was determined from a

TABLE I—Identification and Chemical Analysis of The Cast and Wrought Steels Tested in Preliminary Tests

Steel Number	Steel	C	Mn	Si	P	S	Remarks
1	Cast 1020	.19	.74	.40	.012	.023	1" Coupons
2	Cast 1030	.29	.71	.58	.024	.030	1" Coupons
3	Cast & Wrought 1030	.29	.71	.58	.024	.030	Steel 2 Hot Rolled to 7/8" Round
4	Wrought 1030	.29	.48	.14	.010	.041	Commercial Hot Rolled 1" Round
5	Wrought 1030	.29	.45	.02	.007	.065	Commercial Hot Rolled 1 1/4" Round
6	Wrought 1040	.40	.79	.26	.017	.027	Commercial Hot Rolled 2" Round

Table II—Tensile, Hardness and Fatigue Test Results for Steels Used in Preliminary Study

Steel Number	Steel	Tensile Strength, 1000 Psi	0.2% Yield Strength, 1000 Psi	Reduction in Area, Per Cent	Elongation in 2" Per Cent	Brinell Hardness Number	Endurance Limit, 1000 Psi	Unnotched Endurance Ratio
1	Cast 1020	68.7	42.0	54.4	31.0	143	32.0	.47
2	Cast 1030	83.2	49.9	41.2	27.7	163	40.0	.48
3	Cast & Wrought 1030	84.3	53.8	60.0	31.7	163	45.0	.53
4	Wrought 1030	68.3	44.1	62.2	34.5	133	35.0	.51
5	Wrought 1030	65.9	32.2	55.7	34.2	121	28.7	.44
6	Wrought 1040	84.8	53.0	58.1	30.5	169	40.0	.47

NOTE: All steels were normalized and tempered before machining and testing. Normalizing temperature 1650°F, one hour. Tempered one hour at 1200°F, Air cool.

* The endurance limit of a metal is the stress below which the metal will not fail if subjected to an indefinitely large number of cycles of stress.

complete S-N curve‡ for each steel. The individual S-N curves for each steel are shown in Figure 1. The most significant points of the curves are those near the endurance limit or flat portion of the curve. The endurance limit of the cast 1030 steel and commercial wrought 1040 steel was identical. The rolled 1030 steel (No. 3) from the same heat as the cast 1030 had a higher endurance limit. The other commercial wrought 1030 steels (No. 4 & 5) show considerable differences in fatigue properties; the endurance limit of one 1030 (No. 5) wrought steel is lower than the cast 1020 steel.

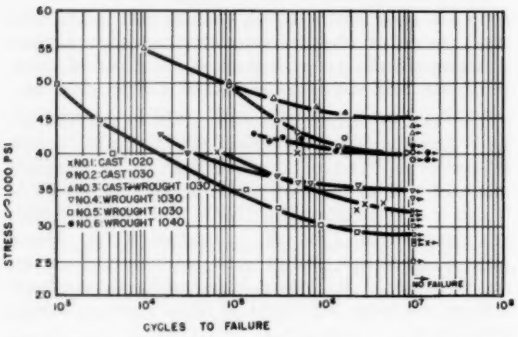


Figure 1—S-N curves for several cast and wrought steels normalized and tempered.

Observations made from the preliminary study are as follows:

(1) The fatigue properties of carbon cast steels compare favorably with the fatigue properties of wrought steels of similar carbon content.

(2) The tensile and fatigue properties of the commercial wrought 1030 steels do not agree.

(3) The scatter of data for the wrought steels can be attributed almost entirely to the different steelmaking practices; therefore, future fatigue work with the wrought steels requires that the wrought steel should be made with standard deoxidation practices.

(4) The mechanical properties of the cast 1030 steel compare favorably with the wrought 1040 steel.

The research studies on all the four phases have been completed at Case Institute of Technology and an extensive report has been submitted. The Technical Research Committee has completed its review of the studies and has scheduled publication of the report as a blue book report this fall. The report is better than half completed at the time of publication of this Journal.

A sum of $20,000 was appropriated for the studies of Project No. 25. The total expenses to date are $14,275.22. Publication costs will be a sizeable figure and will take a large portion of the remaining $5,724.88 unexpended funds.

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TS 8630 CAST STEEL

(Continued from Page 10)

are a major concern. The impact properties of the TS 8130 and TS 8630 show a marked improvement in the quenched and tempered condition over the values obtained by normalizing and tempering.

From the results of this investigation the following conclusions may be drawn:

(1) The three substitute cast steels are rated in order of increasing hardenability as: (1) TS 8130, (2) TS 6130 and, (3) TS 8630. See Figure 4.

(2) The TS 8630 steel exhibited a slightly better combination of strength and ductility in the tensile test.

(3) The impact properties of the TS 8630 and TS 8130 steels were about the same and were much superior to those of the 6130 steel.

(4) The difference in properties between the one-inch and four-inch sections indicated that the mass effect was small.

(5) Only the impact properties seem to be influenced by the melting process, i.e., in general, the basic process gave higher values for the TS 8630 and TS 8130 steels. When the impact values were poor as for the 6130 steel, the basic process did not offer any appreciable advantage.

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Unitcast Corporation
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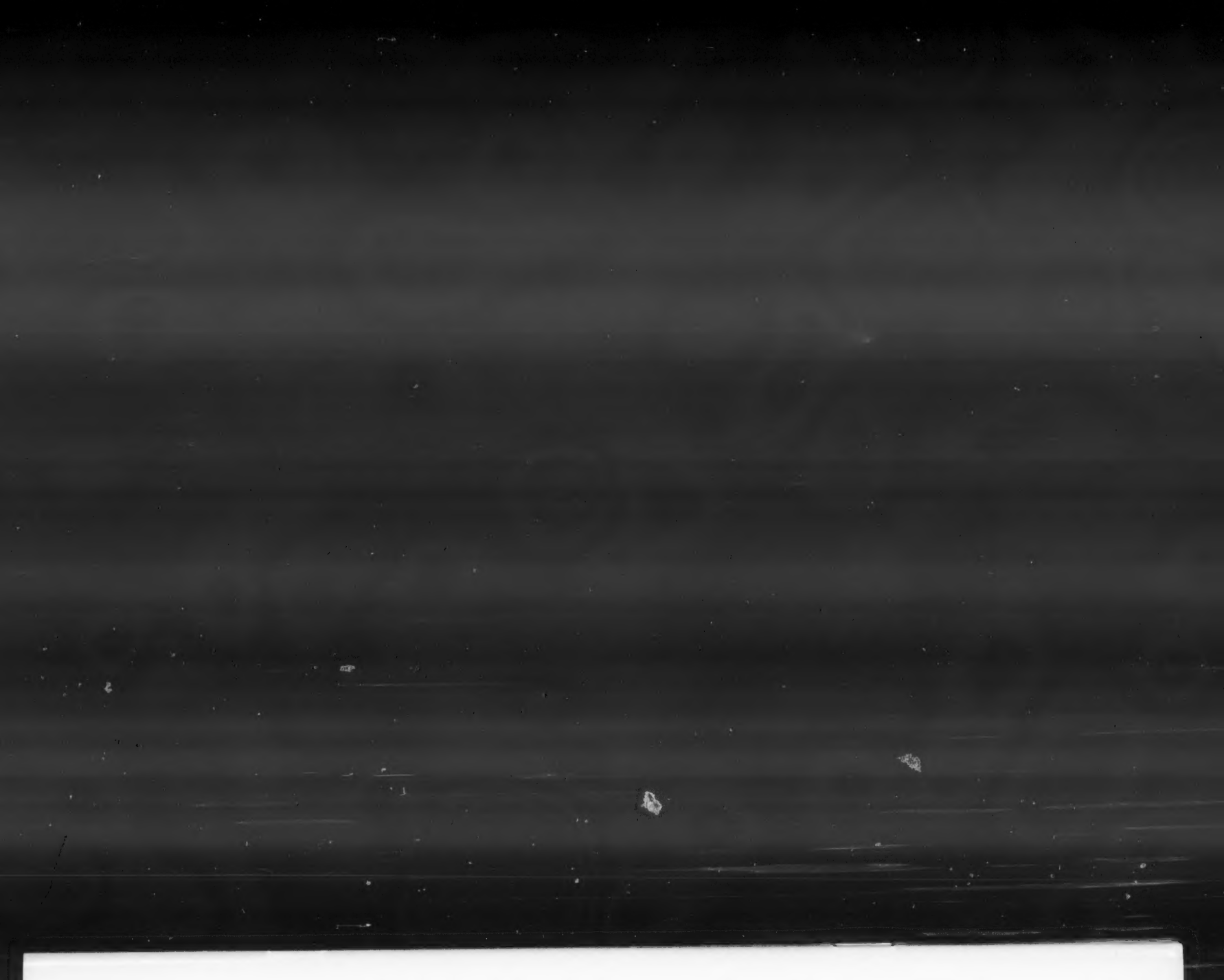
‡ Applied stress plotted against number of cycles to failure.